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Title:
Collaborative Research: Dynamics of Ocean Climate Changes in the Gulf of Alaska

Project Participants

Senior Personnel

Name: Di Lorenzo, Emanuele
Worked for more than 160 Hours: Yes
Contribution to Project:

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Worked for more than 160 Hours: Yes
Contribution to Project:

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Research Experience for Undergraduates

Organizational Partners

Scripps Institution of Oceanography

NOAA/Climate Diagnostics Center

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:
see attached file in findings

Findings:
see attached file in findings

Training and Development:
see attached file in findings

Outreach Activities:
see attached file in findings

Journal Publications

Combes V. and E. Di Lorenzo, "Intrinsic and forced interannual variability of the Gulf of Alaska mesoscale circulation", Progress in Oceanography, p. , vol. 75(2), (2007). Published,

Combes V., E. Di Lorenzo and E. Curchister, "Interannual and decadal variations in cross-shore mixing in the Gulf of Alaska", Journal of Physical Oceanography, p. , vol. , (2009). Published, 10.1175/2008JPO4014.1

Di Lorenzo E., Schneider N., Cobb K. M., Chhak, K, Franks P. J. S., Miller A. J., McWilliams J. C., Bograd S. J., Arango H., Curchister E., Powell T. M. and P. Rivere, "North Pacific Gyre Oscillation links ocean climate and ecosystem change", Geophysical Research Letters, p. , vol. , (2008). Published, 10.1029/2007GL032838

Di Lorenzo E., Fiechter J., Schneider N., Miller A. J., Franks P. J. S., Bograd S. J., Moore A. M., Thomas A., Crawford W. and Pena and Herman A., "Nutrient and Salinity Decadal Variations in the central and eastern North Pacific.", Geophysical Research Letters, p. , vol. , (2009). Published, 10.1029/2009GL038261

Chhak, K., E. Di Lorenzo, N. Schneider and P. Cummins, "Forcing of low-frequency ocean variability in the Northeast Pacific", Journal of Climate, p. , vol. , (2009). Published, 10.1175/2008JCLI2639.1

Capotondi, A., V. Combes, M. A. Alexander, E. Di Lorenzo and A. J. Miller, "Low-Frequency Variability in the Gulf of Alaska from coarse and eddy-permitting ocean models.", Journal of Geophysical Research, p. , vol. , (2009). Published, 10.1029/2008JC004983

Books or Other One-time Publications

Web/Internet Site

URL(s):
http://www.o3d.org/npgo
Description:

Other Specific Products

Contributions

Contributions within Discipline:

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Any Book
Any Product
Contributions: To Any within Discipline
Contributions: To Any Other Disciplines
Contributions: To Any Human Resource Development
Contributions: To Any Resources for Research and Education
Contributions: To Any Beyond Science and Engineering
Any Conference

Collaborative Research: Dynamics of Ocean Climate Changes in the Gulf of Alaska

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Final Report to NSF

May 27, 2009

During the course of research, which lasted three years with an additional one-year NCE, we studied many important topics associated with the Gulf of Alaska (GoA) circulation, as previously explained in the annual reports. We here list the publications that resulted from this work, with brief synopses of the high points of a few key papers.

1. Adjustment of the circulation in the GoA to changing wind forcing

An important issue is how the circulation in the GoA responds to wind forcing changes when eddies are present. We previously had examined coarse resolution runs that contained topographic Rossby waves that propagated along the shelf-slope from the eastern basin to the western basin. These seemed to be more important than the interior ocean Rossby waves in connecting eastern and western ocean margins. In the interior, upper-ocean density variations were highly correlated with the local Ekman pumping forcing. The high-resolution model had many features in common with the coarse resolution run. A strange part of the response was the lack of direct relationship between pycnocline depth and sea level height under many circumstances, indicating that altimetry cannot explain the full subsurface dynamical response in the GoA. The eddy kinetic energy in the GoA was related to PDO forcing, while pycnocline depth variability was more controlled by NPGO forcing. These topics were addressed in detail by:

Capotondi, A., V. Combes, M. A. Alexander, E. Di Lorenzo and A. J. Miller, 2009: Low-frequency variability in the Gulf of Alaska from coarse and eddy-permitting ocean models. *Journal of Geophysical Research-Oceans,* 114, C01017, doi: 10.1029/2008JC004983.

Abstract: An eddy-permitting ocean model of the northeast Pacific is used to examine the ocean adjustment to changing wind forcing in the Gulf of Alaska (GOA) at interannual-to-decadal timescales. It is found that the adjustment of the ocean model in the presence of mesoscale eddies is similar to that obtained with coarse-resolution models. Local Ekman pumping plays a key role in forcing pycnocline depth variability and, to a lesser degree, SSH variability in the center of the Alaska gyre and in some areas of the eastern and northern GOA. Westward Rossby wave propagation is evident in the

SSH field along some latitudes, but is less noticeable in the pycnocline depth field. Differences between SSH and pycnocline depth are also found when considering their relationship with the local forcing and leading modes of climate variability in the northeast Pacific. In the central GOA pycnocline depth variations are more clearly related to changes in the local Ekman pumping than SSH. While SSH is marginally correlated with both Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) indices, the pycnocline depth evolution is primarily related to NPGO variability. The intensity of the mesoscale eddy field increases with increasing circulation strength. The eddy field is generally more energetic after the 1976-77 climate regime shift, when the gyre circulation intensified. In the western basin, where eddies primarily originate from intrinsic instabilities of the flow, variations in eddy kinetic energy (EKE) are statistically significant correlated with the PDO index, indicating that eddy statistics may be inferred, to some degree, from the characteristics of the large-scale flow.

2. Intrinsic versus forced variability in the GoA

It was unclear, before this research commenced, what parts of the GoA circulation were dominated by atmospheric forcing and what parts were associated mainly with instabilities of the ocean currents. We showed, using three realizations of a 50-yr eddy resolving model, that eastern basin response on interannual timescales is dominated by atmospheric forcing, while the western basin response is dominated by internal eddy variability. The details of this and other aspects of response are explained in:

Combes, V. and E. Di Lorenzo, 2007: Intrinsic and forced interannual variability of the Gulf of Alaska mesoscale circulation. *Progress in Oceanography*, doi:10.1016/ j.pocean.2007.08.011.

Combes, V., E. Di Lorenzo and E. Curchister, 2009: Interannual and decadal variations in cross-shore mixing in the Gulf of Alaska. *Journal of Physical Oceanography*, 39(4), 1050-1059, DOI: 10.1175/2008JPO4014.1.

Abstract: The response of the Gulf of Alaska (GOA) circulation to large-scale North Pacific climate variability is explored using three high-resolution (15 km) regional ocean model ensembles over the period 1950–2004. On interannual and decadal timescales the mean circulation is strongly modulated by changes in the large scale climate forcing associated with PDO and ENSO. Intensification of the model gyre scale circulation occurs after the 1976–1977 climate shift, as well as during 1965–1970 and 1993–1995. From the model dynamical budgets we find that when the GOA experiences stronger southeasterly winds, typical during the positive phase of the PDO and ENSO, there is net large-scale Ekman convergence in the central and eastern coastal boundary. The geostrophic adjustment to higher sea surface height (SSH) and lower isopycnals lead to stronger cyclonic gyre scale circulation. The opposite situation occurs during stronger northwesterly winds (negative phase of the PDO).

Along the eastern side of the GOA basin, interannual changes in the surface winds also modulate the seasonal development of high amplitude anticyclonic eddies (e.g. Haida and Sitka eddies). Large interannual eddy events during winter-spring are phase-locked with the seasonal cycle. The initial eddy dynamics are consistent with a quasi-linear Rossby wave response to positive SSH anomalies forced by stronger downwelling favorable winds (e.g. southwesterly during El Nino). However, because of the fast growth rate of baroclinic instability and the geographical focusing associated with the coastal geometry, most of the perturbation energy in the Rossby wave is locally trapped until converted into large scale nonlinear coherent eddies. Coastally trapped waves of tropical origin may also contribute to positive SSH anomalies that lead to higher amplitude eddies. However, their presence does not appear essential. The model ensembles, which do not include the effects of equatorial coastally trapped waves, capture the large Haida and Sitka eddy events observed during 1982 and 1997 and explain between 40% and 70% of the tidal gauges variance along the GOA coast.

In the western side of the GOA basin, interannual eddy variability located south of the Alaskan Stream is not correlated with large scale forcing and appears to be intrinsic. A comparison of the three model ensembles forced by NCEP winds and a multi-century-long integration forced only with the seasonal cycle shows that the internal variability alone explains most of the eddy variance. The asymmetry between the eddy forced regime in the eastern basin, and the intrinsic regime in the western basin, has important implications for predicting the GOA response to climate change. If future climate change results in stronger wintertime winds and increased downwelling in the eastern basin, then increased mesoscale activity (perhaps more or larger eddies) might occur in this region. Conversely, the changes in the western basin are not predictable based on environmental forcing. Eastern eddies transport important biogeochemical quantities such as iron, oxygen and chlorophyll-a into the gyre interior, therefore having potential upscale effects on the GOA high-nutrient-low-chlorophyll region.

3. Large-scale climate controls on the GoA: The NPGO

Perhaps the most influential result of our research is the identification of the North Pacific Gyre Oscillation as a controlling mode of variability in the North Pacific. It represents the oceanic response to the North Pacific Oscillation in sea level pressure, which has long been known in the literature. The modal structure include a SST temperature pattern that has previously been called the “Victoria Mode” and a sea-level height pattern, that has been previously called the “Breathing Mode”, but the relations between these previous studies was never noted until now. The truly remarkable result is that the NPGO clearly is related to salinity variations in the CCS and GoA, whose variations have never before been so clearly explained. Moreover, numerous biologically relevant variables, such as nutrients and phytoplankton content are also related to the NPGO. Although many more papers are coming out relating various aspects of response to the NPGO, the basic details are fully explained in these two papers:

Di Lorenzo, E., N. Schneider, K. M. Cobb, P. J. S. Franks, K. Chhak, A. J. Miller, J. C. McWilliams, S. J. Bograd, H. Arango, E. Curchitser, T. M. Powell and P. Riviere, 2008: North Pacific Gyre Oscillation links ocean climate and ecosystem change. *Geophysical Research Letters,* 35, L08607, doi:10.1029/2007GL032838.

Abstract: Decadal fluctuations in salinity, nutrients, chlorophyll, a variety of zooplankton taxa, and fish stocks in the Northeast Pacific are often poorly correlated with the most widely used index of large-scale climate variability in the region - the Pacific Decadal Oscillation (PDO). We define a new pattern of climate change, the North Pacific Gyre Oscillation (NPGO) and show that its variability is significantly correlated with previously unexplained fluctuations of salinity, nutrients and chlorophyll. Fluctuations in the NPGO are driven by regional and basin-scale variations in wind-driven upwelling and horizontal advection, the fundamental processes controlling salinity and nutrient concentrations. Nutrient fluctuations drive concomitant changes in phytoplankton concentrations, and may force similar variability in higher trophic levels. The NPGO thus provides a strong indicator of fluctuations in the mechanisms driving planktonic ecosystem dynamics. The NPGO pattern extends beyond the North Pacific and is part of a global-scale mode of climate variability that is evident in global sea level trends and sea surface temperature. Therefore the amplification of the NPGO variance found in observations and in global warming simulations implies that the NPGO may play an increasingly important role in forcing global-scale decadal changes in marine ecosystems.

Di Lorenzo, E., J. Fiechter, N. Schneider, A. Bracco, A. J. Miller, P. J. S. Franks, S. J. Bograd, A. M. Moore, A. C. Thomas, W. Crawford, A. Pena and A. Hermann, 2009: Nutrient and salinity decadal variations in the central and eastern North Pacific. *Geophysical Research Letters,* **36**, doi:10.1029/2009GL038261.

Abstract: Long-term timeseries of upper ocean salinity and nutrients collected in the Alaskan Gyre along Line P exhibit significant decadal variations that are shown to be in phase with variations recorded in the Southern California Current System by the California Cooperative Oceanic Fisheries Investigation (CalCOFI). We present evidence that these variations are linked to the North Pacific Gyre Oscillation (NPGO) -- a climate mode of variability that tracks changes in strength of the central and eastern branches of the North Pacific gyres and of the Kuroshio-Oyashio Extension (KOE). The NPGO emerges as the leading mode of low-frequency variability for salinity and nutrients. We reconstruct the spatial expressions of the salinity and nutrient modes over the northeast Pacific using a regional ocean model hindcast from1963-2004. These modes exhibit a large-scale coherent pattern that adequately predicts the in-phase relationship between the Alaskan Gyre and California Current timeseries. The fact that large-amplitude, low-frequency fluctuations in salinity and nutrients are spatially phase-locked andcorrelated with a measurable climate index (the NPGO) open new avenues for exploring and predicting the effects of long-term climate change on marine ecosystem dynamics.

4. Intensification of the Alaskan Stream after the 1976-77 Climate Shift

In a previous study of hydrographic observations by Lagerloef (1995, JPO), the Alaskan Stream was noted to have weakened after the 1976-77 climate shift of the North Pacific. This result conflicted with the modeling results we had previously published as well as those that came out of our current research on this grant. In those runs, the Aleutian Low strengthened and the Stream intensified. Interestingly, the observations of dynamic height by Lagerloef agreed with the model results in the interior GoA, but disagreed along the boundary currents. Since a limited number of observations of temperature and salinity profiles were available to Lagerloef, we questioned whether the strength of the Alaskan Stream, which is only about 50km wide, could actually be resolved by Lagerloef's data. Lagerloef generously provided us with the original dynamic height dataset, and we plotted the number of hydrographic profiles in the 4-year epochs that he used to define the strengthening of the Alaskan Stream (Figure 1). Counts rarely exceed 5 in the Stream area for the 4-year epochs. This indicates that Lagerloef's suggestion that the Alaskan Stream weakened after 1976-77 is not significant due to inadequate data. Indeed, cursory inspection of the gridded data, here plotted as averages in 25km squares, suggests an intensification of the Stream (redder values near the northwest boundary), in agreement with the model runs. These results are currently being written up by:

Miller, A. J., G. Auad, A. Capotondi, E. Di Lorenzo, G. Lagerloef and M. Miller-Nicolato, 2009: On the intensity of the Alaskan Stream after the 1976-77 climate shift. In preparation.

5. Additional publications resulting from this collaborative research

We include here the many other publications that acknowledge the support of this grant. For brevity, we do not describe them all. Abstracts and reprints are available from the web pages of Miller and Di Lorenzo.

http://meteora.ucsd.edu/~miller/

http://www.imanu.org/

Alexander, M., A. Capotondi, A. Miller, F. Chai, R. Brodeur and C. Deser, 2008: Decadal variability in the Northeast Pacific in a physical-ecosystem model: Role of mixed layer depth and trophic interactions. *Journal of Geophysical Research-Oceans,* **113**, C02017, doi:10.1029/2007JC004359.

Auad, G. and A. J. Miller, 2008: The role of tidal forcing in the Gulf of Alaska's circulation. *Geophysical Research Letters,* **35**, L02602, doi:10.1029/2007GL031611.

Auad, G., 2008: Response of the Gulf of Alaska 3D winter circulation to oceanic climate shifts: Ecosystem implications. *Geophysical Research Letters*, **35**, 10.1029/2007GL031611

Chhak, K., E. Di Lorenzo, N. Schneider and P. Cummins, 2009: Forcing of low-frequency ocean variability in the Northeast Pacific. *Journal of Climate*, DOI: 10.1175/2008JCLI2639.1

Overland, J., J. Alheit, A. Bakun, J. Hurrell, D. L. Mackus and A. J. Miller, 2009: Climate controls on marine ecosystems and fish populations. *Journal of Marine Systems,* in press.

Miller, A. J., E. Di Lorenzo, D. J. Neilson, H.-J. Kim, A. Capotondi, M. A. Alexander, S. J. Bograd, F. B. Schwing, R. Mendelssohn, K. Hedstrom and D. L. Musgrave, 2005: Interdecadal changes in mesoscale eddy variance in the Gulf of Alaska circulation: Possible implications for the Steller sea lion decline. *Atmos.-Ocean,* 43, 231-240.

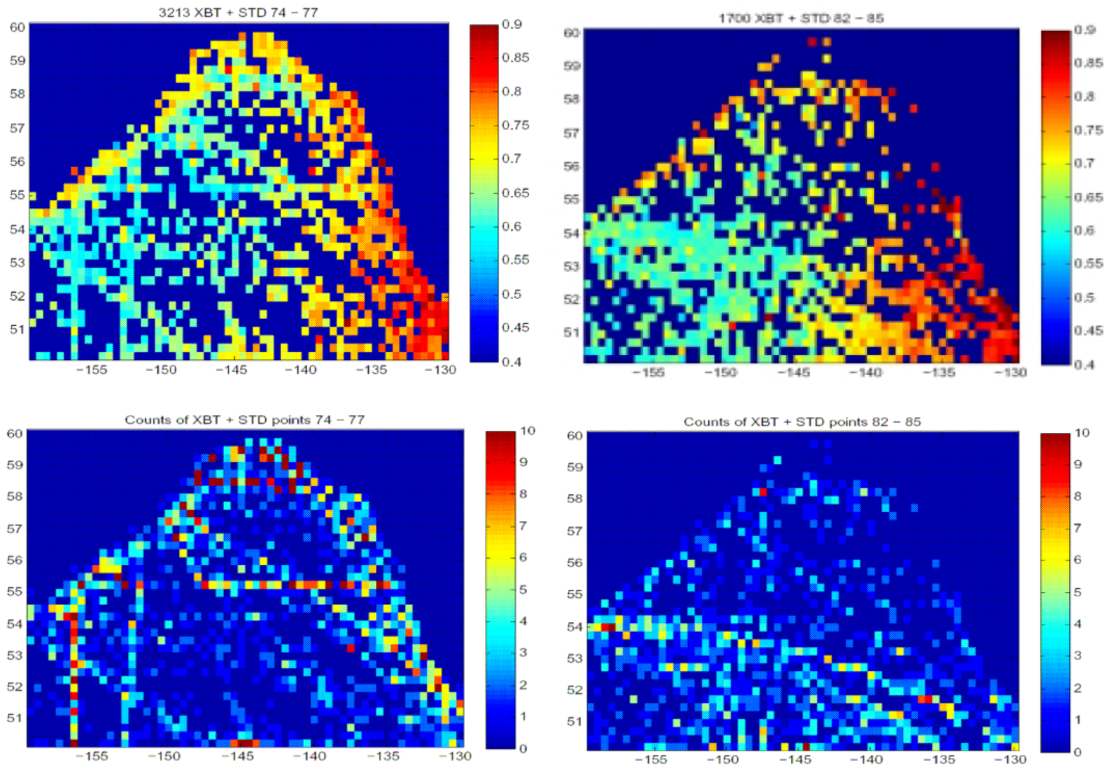

Figure 1. (Top) Dynamic height in the GoA on a 25km grid for (left) 1974-77 and (right) 1982-85. Values are averages based on the Lagerloef calculation of DynHt from XBT and CTD. Grid points with no data are dark blue. (Bottom) Number of stations contributing to the average DynHt computed above them. Counts rarely exceed 5 in the Stream area for the 4-year epochs. This indicates Lagerloef's suggestion that the Alaskan Stream strengthened after 1976-77 is not significant due to inadequate data.